Bakerian Lecture: *Series Lines in Spark Spectra.*

By A. Fowler, F.R.S., Assistant Professor of Physics, Imperial College, South Kensington.

(Lecture delivered April 2,—MS. received April 20, 1914.)

(Abstract.)

The classical work of Rydberg, and that of Kayser and Runge, dealt chiefly with series lines occurring in spectra which are produced in the electric arc, or in vacuum tubes with discharges of moderate intensity. In the present communication the lines considered are some of those which are specially developed in the condensed spark; that is, lines which belong to the class of "enhanced lines" as defined by Lockyer.

The investigation was undertaken in connection with the new lines (λ 4686, etc.) which were produced in 1912 by passing strong discharges through helium tubes, which always contained an impurity of hydrogen.* These lines are of great interest in celestial spectroscopy, and, following Rydberg, they were at first attributed to hydrogen; they appeared to be closely related to the hydrogen series, while showing no relation to the known series of helium. In addition to the lines calculated by Rydberg for the "Principal" series of hydrogen, however, the "4686" series included an intermediate series which the recognised formulæ suggested was a second "Principal" series, having a simple relation to the first. As the lines could not be obtained from hydrogen alone, it was soon felt that further enquiry should be made as to the value of the numerical evidence on which their assignment to hydrogen was chiefly based. A search for other series of similar character was therefore instituted in the hope that some generalisation with regard to them might be reached.

The conditions of appearance of the lines in helium tubes suggested spark spectra as the most promising source of such series, and a subsequent investigation of magnesium showed that the well-known spark line λ 4481 was the first member of a series of the kind looked for. No satisfactory evidence of relation to other series of magnesium was then obtained, and it seemed possible that both the "4686" and the "4481" series might be of a new type, having no necessarily simple relation to other series in the respective spectra.†

The lines of the "4686" series, and the associated "Pickering" series, have

* 'Monthly Notices Roy. Astro. Soc.,' vol. 73, p. 62 (December, 1912).

† 'Roy. Soc. Proc.,' A, vol. 89, p. 133 (June, 1913).

since become of increased importance, in connection with theories of the constitution of the atom, through the theoretical investigations of Dr. Bohr, who explains them as being produced during the first stage in the re-formation of atoms of helium from which both electrons have been removed by the strong discharges employed. Bohr's formula for this series is identical, in a first approximation, with that for hydrogen, except that the Rydberg constant N (= 109,675 for Rowland's scale) has four times its usual value. The two "Principal" series previously assigned to hydrogen were thus united in a single series of a new type, while the Pickering series was made to include additional lines nearly coincident with the Balmer series of hydrogen. It therefore became important to ascertain if such a modified formula could be adapted to the analogous "4481" series of magnesium, and to other series of spark lines if they could be found.

Further investigation of magnesium was also suggested by Dr. King's discovery that the line 4481 is a very close doublet. Two additional members of this series were resolved, and it at once appeared that the series was not of the ordinary Principal type. The new measurements also showed that the eight observed lines could be united in a single series of the new type suggested by the work of Dr. Bohr. Other series of the same kind were found in Lyman's observations of certain "narrow" doublets in the spectra of calcium, strontium, and barium in the Schumann region.

At this stage a valuable contribution to the investigation was made by the work of E. Lorenser,* who had discussed the Lyman lines, and had shown that they formed series of the Fundamental (or "Bergmann") type, associated with the wider doublets which occur in the spectra of these elements. Lorenser does not appear to have recognised that the lines in question belong to the special class of enhanced lines, but his work proved that these lines form a new class of series, and that similar groups of series occur both in arc and spark spectra. The formula employed by Lorenser was of a modified Rydberg form, but further calculations have shown that the individual series, and the relation between the different series of the same element, are better represented by the Hicks formula with 4N for numerator. One peculiarity of these series is that the first pair of the Diffuse series occurs with a negative sign in the formulæ, whereas it appears in arc series as a positive term.

The wider doublets which occur in the spectrum of magnesium are in several respects analogous to the wider doublets of calcium, strontium, and barium, but the negative term of the Diffuse series is lacking, and a Fundamental series which would fall in line with those of the other three elements is also wanting. The use of the Hicks formula shows that the

* 'Dissertation,' Tübingen, 1913.

limit of the "4481" series is related to the first *positive* term of the Diffuse series, but the fact that the doublets occur both in arc and spark, while 4481 requires spark conditions, indicates that the relation is probably indirect.

The character of the spark series system of magnesium has been elucidated by the discovery of a new group of series of narrow doublets, which occur under exactly the same experimental conditions as 4481. Two of these pairs were observed by Fowler and Payn in 1903, and for convenience of reference the new group of series has been designated the "FP" system. It is shown that the "4481" series is the Fundamental series of this group, its limit being derived from the first negative term of the Diffuse series, as in the case of calcium, strontium, and barium. There is evidence that corresponding series in the "FP" and wide doublet systems run parallel to each other, so that data lacking in one may be obtained from observations of the other. Thus it is found that the separation of the "FP" doublets is equal to the calculated separation of the *second* Principal pair of the wide doublets, which lies in the Schumann region and has not yet been observed. Two well-defined combination series, each consisting of seven lines, have also been recognised in the course of the experiments on magnesium, one derived from terms of the Diffuse and "4481" series, and the other entirely from the "4481" series.

From these investigations it follows that two kinds of series have now to be recognised: (1) series of the "arc" type, having Rydberg's N for the series constant; and (2) series of the "spark" or "enhanced line" type, having a series constant equal to 4N. No numerical relations have yet been traced between the two sets of series occurring in the spectrum of the same element.

Returning to the lines produced in helium tubes, it is now clear that the line 4686 and the other lines associated with it form a single series of the enhanced line (4N) type, and that they can no longer be considered to belong to the same group as the Balmer series of hydrogen, which is of the arc (N) type. The close numerical relations indicated by Rydberg's calculations are therefore not significant, and, in view of the experimental evidence, it must be concluded that the "4686" series is not due to hydrogen but to helium, as first suggested by Dr. Bohr from theoretical considerations. In accordance with the convenient nomenclature of Lockyer, they may be designated "proto-helium" lines. Analogy with the "4481" series of magnesium suggests that the "4686" series is primarily of the Fundamental type, while the three associated series may be considered to be coincident with it.

If the Pickering lines are also due to proto-helium, as seems probable, the series must include additional lines which are almost superposed on the

Balmer series. Experimental and astronomical evidence on this point is incomplete, but there is no evidence against this supposition. The assignment of the Pickering lines to proto-helium is supported by the observations of magnesium, since one of the new combination series is related to the "4481" series in exactly the same way that the extended Pickering series would be related to the "4686" series.

The close relations between the lines of hydrogen (real and hypothetical) and some of those of proto-helium is simply accounted for by Bohr's theory of the origin of these spectra. The formulæ, in which p and m can only take integral values, may be written—

Hydrogen ..... $n = \mathrm{N}\left(\frac{1}{p^2}-\frac{1}{m^2}\right)$. $p = 2$ for Balmer series.

Proto-helium... $n = \mathrm{N}'\left(\frac{1}{p^2}-\frac{1}{m^2}\right)$. $\begin{cases} p = 3 \text{ for "4686" series.} \\ p = 4 \text{ for Pickering series.} \end{cases}$

If N′ were exactly equal to 4N, some of the lines of proto-helium would be coincident with those calculated by Rydberg for the Principal series ($p = 1{\cdot}5$ in the first formula) and for the Sharp series of hydrogen ($p = 2$, $m = m + 0{\cdot}5$ in the first formula). The observed values are $\mathrm{N} = 109{,}675$, $\mathrm{N}' = 438{,}879{\cdot}1 \pm 1{\cdot}0$ (the latter from $\lambda\, 4685{\cdot}98 \pm 0{\cdot}01$), and Bohr has shown that their ratio is in very close agreement with his theoretical expressions for these terms when correction is made for the mass of the electron. The above values of N and N′ give a provisional value for the mass of the hydrogen atom in terms of that of the electron as 1836 ± 12; or 1855 ± 12 when the data are corrected to the International scale of wave-lengths.

The well-known line at 4686 which occurs in the solar chromosphere, and in some of the nebulæ, is undoubtedly the proto-helium line, and there are no indications in these spectra of another line at 4688 which would correspond with the calculated Principal line of hydrogen. Until other evidence is forthcoming, it may be considered that the line spectrum of hydrogen consists only of the Balmer series and parallel series in the infra-red and Schumann regions.

In regard to more complex spectra, since N and 4N are constant, or nearly so, for the two classes of series, Bohr's theory suggests that arc series in general are produced by atoms from which only one electron has been removed by the exciting source, while spark series are produced when two electrons have been removed. It has not yet been shown, however, how a single series of hydrogen or of proto-helium comes to be represented by a group of series in other spectra.

The change in the character of the series in passing from arc to spark spectra suggests the possibility of further change in the same direction, leading to series which would require nine times the ordinary series constant in the formulæ representing them. A preliminary examination of terrestrial and celestial spectra, however, has given no indications of the existence of such series.

The Emission of Electricity from various Substances at High Temperatures.

By G. W. C. Kaye, B.A., D.Sc., and W. F. Higgins, B.Sc.

(Communicated by R. T. Glazebrook, F.R.S. Received May 1,—Read May 21, 1914.)

(From the National Physical Laboratory.)

Introductory.

In previous papers* an account was given of experiments in which ionisation currents of great magnitude were obtained from carbon at high temperatures. It was remarked that the largest currents appeared to be associated with the expulsion (at about 2000° C.) of impurities, such as silica, alumina and iron, which are always present in commercial carbon. Such a result is perhaps not surprising in view of Wehnelt's† work on the alkaline earths and their large electronic emissivity when raised to a white heat, as for example in a Wehnelt cathode.

Furthermore, Sir J. J. Thomson‡ showed some years ago that oxides, when raised to a red heat in a crucible, gave out an excess of negative electricity, the most copious streams coming from the oxides of calcium and barium.§ The currents generated were such as were readily indicated by an electroscope.

The present experiments (which were carried out some months ago) were undertaken, in the first instance, to investigate the behaviour of the alkaline

* Harker and Kaye, 'Roy. Soc. Proc.,' A, vol. 86, p. 379 (1912); A, vol. 88, p. 522, (1913). King ('Astrophys. Jour.,' Nov., 1913, p. 330) has since repeated some of the experiments at Mount Wilson in connection with his work on "tube-arc" spectra.

† Wehnelt, 'Ann. d. Phys.,' vol. 14 (4), p. 425 (1904), and 'Phil. Mag.,' July (1905). See also Jentzsch, 'Ann. d. Phys.,' vol. 28, p. 537 (1909).

‡ J. J. Thomson, 'Camb. Phil. Soc. Proc.,' vol. 14, p. 105 (1906).

§ Prof. Thomson showed further that when various salts were heated, the sign of the resulting electrification was the same as that produced by friction of the dry salt when cold.